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A State- of-The-Art Technical Review on Seismic Resilience of Rcc Structural Components Using Seismic Resistance Based Retrofitting Techniques.

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Abstract:

Existing buildings can be at a greater seismic risk due to non-conformance to current design codes and may require structural retrofitting to improve building performance. The most recent example of that can be seen from the 2015 AD earthquake in Nepal and other sub continental regions, where numbers of buildings were destroyed with more fatal consequences have drawn the attention of the government authorities of Nepal and the general public for seismic earthquake resistance design of buildings. Following the post seismic assessment of building in Nepal after 2015 earthquake, it is revealed that the existing reinforced concrete buildings have some inadequacies in structural components and thus the intensive research and study is required to for the better understanding of the structure in terms of immediate consequences due to direct damage and way to recovery using seismic retrofit assessment.

This paper presents an overview on performance based evaluation of retrofitted rcc structural member using some advanced retrofitting techniques which is innovative and can be cost effective retrofitting strategies demanding less skilled man power. It is concluded that better seismic resilience can be achieved with the help of innovative methods with the application of innovative materials like textile mortars and fibers. In the following sections a review of experimental flexural loading on beam is presented.

Keywords: *Resilience; RCC; performance-based; seismic retrofit; non-ductile*

1. Introduction

Development on civil engineering is indispensable in the present day; hence, it is essential to maintain structure more reliable and effective from cracks, deterioration and other environmental effects. Strengthening of existing structural members is necessary to achieve more service life to the building structure; hence, retrofitting is a process to enhance the structural capacity to withstand more loads that increases the prospect of the building structure to continue survival for more years. Structures may show some sign of distress during their service period and also under the effect of natural calamity like earthquakes, etc. The safety of these buildings is of great concern especially because the loss of most of the lives during collapse of buildings has been reported in the past. The most of the old buildings made are seismic deficient in terms of shear demand and moment capacity and require adequate maintenance. So it is most important to ensure the safety of such buildings against various loads like loads of natural disasters like earthquakes, floods, cyclones and landslides etc. by applying appropriate retrofitting techniques. The term ‘retrofitting’ is mainly used in context with the strengthening of weak buildings to make them strong enough to withstand seismic forces through various repairing methods. The main purpose of retrofitting is to structurally treat the buildings with an aim to restore its 70-80% of its original strength. The main types of damage in reinforced concrete structures are cracking in tension zone, diagonal cracking in the core and loss of concrete cover, stirrups bursting outside and buckling of main reinforcement. The complete replacement of such buildings is just not possible due to a number of social, cultural and financial problems. Therefore, strengthening of existing undamaged or damaged buildings is a definite requirement. It will involve actions for upgrading the seismic resistance of an existing building so that it becomes safer under the occurrence of probable future natural disasters. Different Techniques have been used in the years to restore that structural integrity of the member by restoring or increasing its strength. Researchers across the globe are studying on the retrofitting techniques that are advantageous and most cost effective

2. Literature review

Current research on advanced materials in civil engineering is mainly concentrated on high performance concrete and steel; fibre reinforced polymer (FRP) composites and Textile reinforced mortar (TRM). FRP composite materials have experienced a continuous increase of use in structural strengthening and repair applications around the world in the last fifteen years. High specific stiffness and specific weight combined with superior environmental durability of these materials have made them a competing alternative to the conventional strengthening methods. It was shown through experimental and analytical studies that externally bonded FRP composites can be applied to various structural members including columns, beams, slabs, and walls to improve their structural performance such as stiffness, load carrying capacity, and ductility. FRP composites have enjoyed varying degrees of success in different types of applications. In general, applications that allow complete wrapping of the member with FRP have proven to be effective. Wrapping of columns to increase their load and deformation capacity is the most effective and most commonly used method of retrofitting with composites. However, certain performance and failure mode issues regarding different wrapping configuration and fibre orientations, still need to be well understood. When wrapping is difficult or not allowed, such as when strengthening beams, slabs, or walls, success of the method is sometimes hindered by premature de-bonding failures. Limited research and applications regarding seismic retrofitting of building systems with TRM composites have shown that a composite retrofitting does not significantly alter the stiffness and dynamic properties of the building. The main benefit of retrofitting with composites is the increase in deformation capacity of the building, and in its load capacity to an extent. This may achieve the retrofit objectives for buildings with lightly insufficient seismic resistance. For buildings with large seismic deficiencies, a combination of conventional and FRP/TRM strengthening techniques may prove to be an effective retrofitting solution. FRP/TRM composites and high performance concrete are widely recognized for their potential use in seismic retrofitting applications. To achieve widerange use of these materials, however, there is need for further research into a number of issues related to mechanics, design, and durability of retrofitted concrete. Despite considerable progress in these areas since early last decade further improvements are necessary to meet the needs of the retrofit industry. Failure mechanisms, with emphasis on brittle shear and de bonding failures, must be thoroughly understood and associated design procedures must be incorporated in design codes. Although TRM are known for their favorable durability characteristics, only limited information is available on long-term durability and performance of TRM bonded concrete. These issues need to be investigated through accelerated test studies and related design, application and protection requirements must be included in the design codes. To make the review more comprehensive, it is limited to those investigations which are closely related to these works.

Performance evaluation TRM/FRP

Yadav & Chidambaram(2022)

This research paper presents an experimental study on the cyclic behavior of retrofitted exterior beam-column joints using textile reinforced concrete. Exterior beam-column joint specimens were cast and tested under reverse cyclic loading up to a certain drift and then damaged specimens were retrofitted using textile reinforced concrete (TRC).The cover concrete in the cracked regions were removed and TRC has been used at top and bottom of the joint instead of replacing the core concrete. All the repaired joint specimens were tested under reverse cyclic loading until the complete failure occurs. Hysteresis behavior, energy dissipation and damage index are the parameters used to examine the performance of the retrofitting schemes. It shows that the use of TRC as the external strengthening measures works upto a certain extent compared to the conventional joint interms of energy dissipation and stiffness retention.

Raoof et al. (2017)

This paper compares the flexural performance of RC beams strengthened with TRM and FRP. Thirteen RC beams were fabricated, strengthened and tested in four-point bending. One beam served as control specimen, seven beams strengthened with TRM, and five with FRP.

The author concludes TRM being inferior to FRP in enhancing the flexural capacity of RC beams, with the effectiveness ratio between the two systems varying from 0.46 to 0.80. Nevertheless, TRM effectiveness was sensitive to the number of layers. It was found that the effectiveness factor increased from 0.47 to 0.80 when the number of TRM layers increased from 1 to 3. Further coating the carbon fibers textile with epoxy adhesive significantly enhanced the performance of TRM materials. Providing end-anchorage with U-jackets to FRP-retrofitted beams resulted in 90% enhancement in the flexural capacity compared to non- anchorage beam. Two types of failure mode were observed in the FRP-retrofitted beams, these failure modes were: debonding from concrete substrate, and fibers rupture at the constant moment zone. Whereas, in the TRM-retrofitted beams five different failure modes were observed, namely: slippage of the rovings through the surrounding cement mortar, fracture the surface at the textile- matrix interface, debonding of TRM from the concrete with peeling off parts concrete cover, and rupture of the textile fibers at the constant moment zone. These failure modes were found to be sensitive to the number of TRM layers, the textile fibers materials (carbon, coated basalt or glass fibers), and the textile surface condition (dry or coated fibers). The research gap found in this study is summarized below.

- The paper does not consider the cost-effectiveness of the TRM and FRP retrofitting methods. Although the FRP is found to be more effective in enhancing the flexural capacity of the beams, it is also known to be more expensive than TRM. Therefore, it may be of interest to investigate the cost-benefit ratio of both techniques and to identify the most appropriate retrofitting method for different types of structures and applications.

Tetta et al.(2015)

This paper presents an experimental study on shear strengthening of rectangular reinforced concrete beams with advanced composite materials i.e. TRM and FRP. 14 RC beams were constructed and tested under bending loading. One of the beams did not receive any strengthening and served as control beam, eight received TRM jacketing, whereas the rest five received FRP jacketing. Reinforced beam was again subjected to 4-point bending.

It is concluded that the TRM is generally less effective than FRP in increasing the shear capacity of concrete, however the effectiveness depends on both the strengthening configuration and the number of layers. U-wrapping (UW) strengthening configuration is much more effective than side-bonding (SB) in case of TRM jackets. On the contrary, in case of FRP jackets the UW configuration was found only slightly more effective than the SB configuration. A major difference between TRM and FRP strengthening systems is observed by increasing the number of layers.

Author suggests future research should be directed towards investigating a wide range of jackets reinforcing ratio for different strengthening configurations, as well as testing of full-scale beams retrofitted with TRM jackets. The research gap found in this study is summarized below.

- The study was conducted on small-scale RC beams, and the results may not be directly applicable to full-scale beams. Future research can investigate the behavior of full-scale RC beams strengthened with TRM jackets, and compare the results with those obtained from small-scale experiments.
- Investigation of the effect of different loading conditions: The study investigated the behavior of RC beams under 4-point bending loading. However, RC beams may be subjected to different loading conditions, such as axial compression or torsion, which can affect the effectiveness of the strengthening techniques. Future research can investigate the behavior of RC beams under different loading conditions, and evaluate the effectiveness of TRM and FRP jackets in these cases.

Gideon & Alagusundaramoorthy (2018)

This paper presents retrofitting of RC beams using CFRP laminates. The beams of dimensioning 5000 mm, 400 mm, and 230 mm were reinforced identically with two 12 mm diameter bars in tension zone and two 10 mm diameter bars in compression zone. Four reinforced concrete beams were prepared, among which two were taken as control specimen and other two beams were retrofitted by bonding 50 mm wide and 1.4 mm thick CFRP laminate on the tension zone with external bonding. All the specimens were tested up to failure. From the test they found retrofitted specimens showing an increase in ultimate load carrying capacity and stiffness up to 53% and 61% respectively. The debonding of CFRP laminate started from a flexural crack below loading point and propagates towards the support of RC beam. The retrofitted specimens failed by interfacial crack induced debonding failure mode at a strain of 25% of CFRP laminate's rupture strain. The capacity if the CFRP laminate is underutilized in externally bonded RC beams. The Stiffness, yield load, and ultimate load were increased upto 61%, 47%, and 53% respectively on RC beams retrofitted with CFRP laminate compared to the corresponding control beams. Author concludes that CFRP laminates are to be anchored on RC beams along with bonding using adhesives. The research gap found in this study is summarized below.

- Future research could consider the anchorage of CFRP laminates on RC beams along with bonding using different adhesives for the better performance.

Kumar & Modi (2017)

This paper describes the flexural and shear modes of failure of beam subjected to two-point loading. 24 beams of 1500 x 200 x150 mm were designed using M20 grade concrete and Fe250 steel. Beams were casted and grouped into 4 sets (control beams, CFRP and GFRP strengthened beams and ferrocement strengthened beams). FRP composite comprised of woven fiber mat namely Tyfo SEH 51 (GFRP) and SCH 11 (CFRP) respectively were saturated in epoxy resin and was applied next to surface of the member manually. For ferrocement strengthening cement slurry was applied on the beams for proper bonding between ferrocement laminate and the beam. First crack load is found about 17.3%, 33.1% and 9.5% higher in CFRP, GFRP and ferrocement strengthened beams respectively as compared to control beams. The ultimate load carrying capacity of retrofitted beam specimens is enhanced by about 19%, 31% and 10.4% for CFRP, GFRP and ferrocement strengthened beams respectively. The use of FRP delays initial cracks and further developments of cracks in the beam. Also, ductile behavior of FRP gives enough warning before ultimate failure. GFRP laminates has been found superior to CFRP laminates and ferrocement in enhancing the overall performance of strengthened beams.

Kumara et al. (2018)

This paper presents study of strengthening capacities of externally bonded single layer carbon fibre reinforced polymer (EBCFRP) on reinforced concrete (RC). Control beams and retrofitted beams (both singly laminated and doubly laminated), 3 each were casted and detailed testing was carried out for evaluating load carrying capacity, deflection, cracks, stiffness etc. Each of the beams measured 200 mm*300 mm*2400 mm and were designed based on codal guidelines (IS 456: 2000) provided with 12 mm dia as tensile reinforcement. The beams were subjected to two point bending test set-up. The experimental first crack moment is much higher than the theoretical cracking moment, single laminated beam was found to have 1.88 times higher cracking moment than the control specimen and cracking moment for double laminate beam experienced 2.62 times higher than those without any laminate. For the control specimen covered with laminate on one side the experimental flexural capacity was 1.58 times higher than that of its theoretical counterpart and for the beam covered with laminate on both sides 1.66 times higher flexural capacity was found experimentally. 1.47 times the amount deflection of unlaminated beams as compared to double laminated beam was experienced. Hence, authors found that if only deflection needs to be controlled single laminate would be sufficient. The research gap found in this study is summarized below.

- The study only examines the effectiveness of externally bonded single-layer CFRP, without exploring the potential benefits or drawbacks of using different types of CFRP, such as multiple layers or different fiber orientations.

Er. Gurpreet Singh (2018)

In this paper, twelve beams of size 1000mm * 300mm * 150mm were casted, in which three beams were control beams and rest nine were retrofitted. Two 12mm dia bar was used as tension reinforcement, two 10 mm dia bar was used as compression reinforcement and 8mm dia rings as shear reinforcement with c/c spacing 100mm. The first three beams were tested in four points loading for failure. The rest nine beams were tested in four point loading until cracks appeared on them and these cracked beams were unloaded and retrofitted the cracked beams with unidirectional and bi-directional CFRP sheets having different thickness (six beams were retrofitted with unidirectional CFRP sheets having thickness 0.2mm and 0.3mm and three beams were retrofitted with bi-directional CFRP sheets having thickness 0.4mm). It was observed that the first average crack load of control beams and retrofitted beams were found at 252 KN and above 500 KN respectively. When compared the control RCC beams with the beams retrofitted with uni-directional and bi-directional CFRP sheets, there was increased in ultimate load capacity by 93% and 120% respectively. Debonding between CFRP sheet and concrete occurs at high loads, there occurs debonding at 530 KN in case of uni-directional CFRP sheets whereas 597 KN in bi-directional CFRP sheet, since CFRP sheet shows composite action. Wrapping of CFRP sheets around all four sides of beam is more effective in improving ultimate load capacity of beam and their flexural strength. The research gap found in this study is summarized below.

- The study does not investigate the effect of different adhesive types on the bond strength between the CFRP sheets and the concrete substrate, which is an important factor regarding durability of the retrofitting system.

Nayak et al. (2018)

This paper presents an experimental study on the behaviour of reinforced concrete (RC) beams retrofitted externally with glass fibre reinforced polymer (GFRP) fabrics. Concrete mix design was done for M25 grade concrete according to IS: 10262-2009. All the RC beam specimens of size 120mm×150mm×1000mm provided wirth 4-8mm dia rebar were prepared with M25 grade concrete and Fe415 grade steel. In order to study the structural performance of RC beams strengthened with GFRP fabrics, ten beams were prepared, out of which one without GFRP fabric and the remaining nine beams wrapped with GFRP fabrics wrapped in various lay-up patterns with one, two, three and four layers. All the RC beams were tested under two-point loading in the Universal Testing Machine. The flexural strength of the retrofitted RC beams increases with the increase in number of layers in all the laying patterns. However, the failure pattern gradually changes from ductile to brittle behaviour with increase in the number of layers of GFRP sheet in any lay-up pattern. The beams wrapped with 2 layers GFRP sheets in the tension zone of the beam (bottom portion and half of both sides) shows superior performance with respect to increase in flexural strength, failure pattern and economy in comparison to other retrofitted beams. The research gap found in this study is summarized below.

- Effect of different wrapping techniques (such as bottom face wrapping, U-wrapping, using anchorage) is not considered in ultimate load carrying capacity and failure pattern in RC beam.

Sen et al. (2012)

This paper presents strengthening of RC beams in flexure using natural jute fibre textile reinforced composite system and its comparative study with CFRP and GFRP strengthening systems. The experimental programme contained three beam groups. The beams in group A were designed as controlled specimens, which comprised of two number of RC beam models designated as Con1 and Con2, where no textile FRP application was carried out, the beams in group B were provided with full length wrapping single layer of FRP with full length wrapping 90 degree bonded to the three sides of three beam each using jute textile FRP(JFRP), carbon textile FRP(CFRP), glass textile FRP(GFRP) and group C provided with strip wrapping 90 degree wrapped with materials as of group B beams. Third-point loading system was adopted for the tests. The jute textile FRP exhibited a tensile strength of 189.479 N/mm2, which is 21% of the tensile strength of carbon FRP (923.056 N/mm2) and 28% of the tensile strength of glass (E-glass) FRP (678.571 N/mm2). The jute textile FRP exhibited flexural strength of 208.705 N/mm2, which is 13% of the flexural strength of carbon FRP (1587.134 N/mm2) and 32% of the flexural strength of glass (E-glass) FRP (666.871 N/mm2). The results depicted that JFRP, CFRP and GFRP, strengthening improved the ultimate flexural strength of the RC beams by 62.5%, 150% and 125%, respectively, with full wrapping technique and by 25%, 50% and 37.5%, respectively with strip wrapping technique. JFRP strengthening displayed highest deformability index and proved that jute textile FRP material has huge potential as a structural strengthening material. The research gap found in this study is summarized below.

- Jute is natural fiber which can be found easily and it incurs low cost. Hence, modification of JFRP could be carried out to increase its strength contribution and the applicability of jute textile FRP as a strengthening material.

- The paper only provides data for a specific configuration, not any exploration of the optimal design parameters for jute textile FRP strengthening, such as the number of layers, wrapping technique, and placement of the reinforcement. and further research could help to determine the most effective way to use jute textile FRP in RC beam strengthening.

Raju & Mathew (2013)

This paper investigates the behaviour of beams retrofitted with various natural and synthetic fibres (CFRP, GFRP, SFRP, coir and polypropylene fibre sheets(PFRP)). 30 under reinforced beams (5 control beams and 25 retrofitted beams) of dimensions 150 mm*150 mm*1000 mm were tested under four-point bending. Three bars of 8 mm diameter were used as tension reinforcement and as for shear reinforcement, 6 mm diameter bars were used. All four sides of the beam were wrapped with FRP sheets by roughening the concrete surface first and applying epoxy resin primer. Fibre sheet was then placed on top of epoxy resin coating. All retrofitted beams enhanced the resistance to deflection under applied load. The beams with CFRP sheet wrapping had a better load deflection behavior compared to the other strengthened beams. The highest ultimate load capacity was achieved by CFRP retrofitted beams which is 125% greater than the control specimen. Beams retrofitted with PFRP had the maximum deflections and lower ultimate load carrying capacity which is 37.03% as compared to control beam. The ultimate load capacity of GFRP, SFRP and coir fibre sheet strengthened beams increased by 89.6%, 45.02% and 37.9% respectively. Author concludes that although CFRP retrofitted beam achieved better enhancement in strength, retrofitting using GFRP sheets prove to be economical with significant strength enhancement. The research gap found in this study is summarized below.

- Investigation of the durability of natural fiber over time is not studied which can be scope for further investigation

Aravind et al. (2015)

This paper investigates the flexural strengthening of RC beams retrofitted with corrugated glass fiber reinforced polymer (GFRP) laminates. A total of 21 beams (6 with plain sheets, 12 with corrugated laminates(CL); 6 with and 6 without mechanical fasteners (MF) and 3 control beams) of dimensions 100 mm*150 mm*1200 mm were casted based on IS 456:1978 and tested under four-point bending in 300T UTM. Two bars of 10 mm diameter, two bars of 8 mm diameter were used at bottom and top of the beams respectively and 6 mm diameter two-legged stirrups spaced at 105 mm, all the reinforcements with a characteristic strength of 415 MPa were used. Araldite GY 257 (Epoxy resin) and Aradur 140 (Hardener) were used as adhesives. GFRP plain sheet, 900 mm in length was attached on tension zone of beams as first layer and second layer with the same thickness was attached below the first layer, 112.5 mm in length which extended on the sides of the beam forming a U-wrap which covered 75 % of the overall depth of the beam. Corrugated portion of laminates were filled with epoxy and filler mix and mechanical fastenings were used to connect the extended portion of plain GFRP sheet with the RC beam. The process of application of CL was same as that of plain sheet. For M15 grade concrete strengthened beams, ultimate load of beams strengthened with 300 GSM GFRP CL increased by 13.1% and for beams with CL and MF increased by 22.13% as compared to control beam. For M20 grade concrete, ultimate loads increased by 20.81% and 26.78% for beams with CL and CL with MF 300 GSM GFRP respectively and for 450 GSM GFRP, 7.32% for plain sheet, 31.84% for CL and 39.01% for beams with CL and MF. Beams with CL achieved an ultimate load enhancement upto 11.65%, as compared to the beam with plain sheets for 300 GSM whereas the load capacity was achieved upto 14.95% for 450 GSM, for M15 grade concrete. Similarly, for M20 grade concrete, ultimate load increased upto 14.67%, 22.84% and 26.26% for 300 GSM, 450 GSM and 600 GSM corrugated sheets respectively as compared to that of control beams. Around 90% of the beams showed failure in flexure and not in debonding and rupture of GFRP composites. The study concludes that the load carrying capacity of beams strengthened with GFRP laminates is more than that of beams strengthened with plain sheets and that the increase of GFRP thickness resulted in proportional increase in the load carrying capacity of the beams. The research gap found in this study is summarized below.

- The study only mentions that the beams were strengthened with or without mechanical fasteners, but it does not provide details on the type of fasteners used, their durability, and their long-term effectiveness in enhancing the load carrying capacity of the beams.
- The study mainly focuses on the effect of GFRP laminates' thickness and the addition of mechanical fasteners on the load carrying capacity of retrofitted RC beams. However, it does not explore the impact of various other parameters such as GFRP orientations, and angles of application of GFRP laminates on the performance of retrofitted RC beams.

Tilekar et al. (2017)

This paper presents experimental study on the flexural behavior of GFRP sheets on reinforced beams. Three beams of dimension 2000mm* 200mm*200mm were casted in which two 12mm dia. bar were provided as tension reinforcement , two 12 mm dia. bar were used as compression reinforcement and 2-legged stirrups of 8mm dia with c/c spacing of 200 mm were provided as shear reinforcement. 1st beam was reference beam, 2nd beam and 3rd beam were partially (50%) and fully (100%) wrapped with GFRP sheets. The mix design was done with reference to IS: 10262- 2009 and casting of RC beams were reinforced according to IS 456:2000 code.

The first crack on 1st beam was appeared at 26 KN and the structure failed at 58 KN with maximum deflection of 21.951mm. The first crack on 2nd beam was appeared at 22 KN and the structure failed at 64 KN with maximum deflection of 16.230mm.The first crack on 3rd beam was appeared at 34 KN and the structure failed at 78 KN with maximum deflection of 15.844mm.Author concludes that for beam wrapped with 100% of GFRP and 50% of GFRP, when compared to the strength of control beam, the strength was increased by 34.48% and 10.35% respectively. The research gap found in this study is summarized below.

- The study investigates the flexural behavior of reinforced concrete beams wrapped with GFRP sheets with a limited number of specimens. Future studies can investigate the statistical significance of the findings with a larger sample size.

Dhanaji & Suryawanshi

This paper investigates the behavior of flexural members (RC beam) after strengthening and retrofitting with FRP under the action of vertical transverse load. FRP was applied along the full length all over four sides of flexural RC beam. Six RC beams of dimension 1200mm*150mm*250mm were casted in which two bars of 8mm dia. was used as compression reinforcement, two bar of 10 mm dia. was provided as tension reinforcement and 2-legged stirrups of 6mm dia. bar having 100mm c/c spacing was provided as shear reinforcement. Here one beam was a controlled beam and the rest five were retrofitted (two beams are reinforced with one layer of GFRP sheets and three beams were reinforced with two layers of GFRP sheets). The beams were tested under two point loading flexural test in Universal Testing Machine (UTM).The average ultimate load of beam reinforced with one layer of GFRP sheet was 90 KN which was 30.43% more than that of the control beam and 34.06% less than the reinforced beams with two layers of GFRP sheets. Also the retrofitted beams reinforced with two layers of GFRP sheets had an average ultimate load of 120.66 KN which was 74.88% more than that of the control beams. The inflection of the flexural beam was reduced due to full length wrapping of GFRP sheets along the four sides of the beam. The research gap found in this study is summarized below.

- The study only investigates the effect of retrofitted beams on their ultimate load-carrying capacity. Future studies could also consider serviceability aspects, such as deflection and cracking behavior under sustained loads.

Shinde et al. (2014)

This paper presents study of flexural behavior of reinforced cement concrete beam wrapped with GFRP sheet. The experimental program consists of the testing of 8 R.C.C. beam specimens with dimensions 700mm*150mm*150mm. Out of 8 beams, 4 were designed as under reinforced, reinforced with #2-12 mm diameter bar at bottom, #2-8 mm diameter bar at top using 6mm diameter bars as shear reinforcement. Three main variables namely, strength, ductility and damage level of R.C.C. under reinforced beam and R.C.C. beams weak in flexure were investigated. In the first set of four R.C.C. under reinforced beams two were strengthened with GFRP sheet in single layer from tension face which is parallel to beam axis subjected to static loading tested until failure; the remaining two beams were used as a control specimen. In second set of four beams weak in flexure two were strengthened with GFRP sheet tested until failure; the remaining two were used as a control specimen. In RCC beam, as steel is introduced failure was in the tension zone that is at the bottom zone. Cracking load was observed to be 49.5 KN. In RCC beam, failure was observed in tension zone itself only but observed at the cracking load 102 KN. Cracks got widened at a load of 145 KN. In beam weak in flexure cracking was observed at an average load 41.5 KN. Flexural cracks were observed. In WFR (weak in flexure), the cracking load of 81.75 KN. Due to delamination of FRP, failure was observed after the application of cracking load. Later on spelling of concrete also took place at load of 125 KN. The research gap found in this study is summarized below.

- The study only focused on a limited number of parameters (strength,ductility,damage level) to evaluate the performance of the retrofitting schemes. Future research could consider parameters such as hysteresis behaviour, energy dissipation and crack pattern.
- The paper does not provide a comparative analysis between the results obtained from the use of GFRP sheets and other conventional techniques of strengthening RCC beams, such as steel plates, carbon fiber sheets, or steel fiber-reinforced polymer. Such a comparison could provide a better understanding of the effectiveness and economic feasibility of the GFRP sheet strengthening technique.

Nagaraja et al. (2017)

This paper presents a comparative study of the retrofitting of RC beams under flexural laoding. In this experimental study, the beam design has been carried out as per IS 456-2000 in limit state method. Three reinforced concrete beams with 1500*150*100 mm were casted. Beams were provided with 2 main bars of 8 mm diameter. Among them, one beam was considered as control beam (CB) and the remaining two beams pre cracked to the service load and then retrofitted using the material Fiber Reinforced Polymer (FRP) and High Early Strength Concrete (HSC). The FRP sheets were wrapped to the tension zone of the beam as underlay using epoxy resin. The loads carried, crack width, deflection, mode of failure etc, and were recorded for all the three beams. FRP showed an increase of almost 37% over the load carrying capacity of control beam. HSCB has exhibited an increase of 26% increase in load carrying capacity over the control beam and it is almost nearer to FRP. The cracking moments in FRPRB specimen is higher than than all the beams due to the increase in the moment of inetria of the cross section and and also the flexural tensile strength of CFRP fibres (4900 N/m2) being high in comparison with CB specimen and HSCB specimen. Deflection at ultimate load is higher for FRP as the ultimate strain capacity of FRP is 0.02 and the internal steel reinforcement fractured well before the value is reached. Therefore, the failure strain in internal steel governs the ultimate deflection. The maximum crack width (2.04 mm) in HSCB specimen at failure was lesser than that of the values of the same in CB specimen (2.5 mm) and FRP specimen (3.0 mm). Authors concluded that for retrofitting of RC structures where the increase in flexural strength, stiffness, reduced crack width and better ductility is required, the FRP wrapping can be recommended. Early high strength concrete can be recommended for repair and retrofitting of RC structures where moderate flexural strength, better stiffness, and reduced deflections are required.

Performance evaluation of composite materials

Bashandy(2013)

This study aims to evaluate the efficiency of strengthening reinforced concrete beams using some valid strengthening materials and techniques i.e., concrete layer, reinforced concrete layer and steel plates. Samples are divided into three groups. Group “A” is strengthened using a 2cm thickness concrete layer only. Group “B” is strengthened using a 2cm thickness concrete layer reinforced with meshes (steel and plastic). Group “C” is strengthened using steel plates.

From experimental results it has been seen that using steel plates is more efficient than using reinforced concrete layers by about 300%. Author concluded that using steel mesh increased the ultimate load by about 11-25%.It also enhanced the stiffness and the crack pattern compared to plastic meshes used. From an economic point of view, using steel meshes is considered less costly compared to steel plates by about 60 %. Finally, using steel plates is better than reinforcing meshes. The research gap found in this study is summarized below.

- The study only considered one thickness of concrete layer and did not investigate the effect of varying the thickness. Further research can be done to explore the impact of different thicknesses of concrete layers on the efficiency of strengthening.
- The study primarily focuses on the ultimate load capacity of the strengthened beams. However, the long-term durability and sustainability of the strengthening techniques are equally important.

Nasr(2019)

This paper describes the experimental program carried out in five reinforced concrete beams carried out to investigate the flexural behavior of strengthened RC beams using four different techniques. This technique includes 5cm Ferrocement U-wrapped from three sides, 5cm polypropylene fibers U-wrapped from three sides, one layer U-wrapped of glass fiber reinforced polymers fixed with bolts and four layers U-wrapped of glass fiber reinforced polymers fixed with bolts. This experiment compares between the different strengthening techniques in terms of enhancement of load capacity, first crack load, maximum deflection, Gain in Ductility, Energy Absorption and cost per 1% increase in load capacity. Author concludes that selection of strengthening techniques depends on availability of materials used, construction, life cycle costs, percentage of strength increase, etc. GFRP has mechanical strength, low maintenance, anti magnetic, fire resistant, good electrical insulator and weatherproof. The strengthened beam shows a decrease in cracks width, significant change in ductility ratio, decrease in deflection compared with control beams and considerable increase in energy absorption.

Torres et al. (2021)

This paper furnishes the experimental results obtained from tests on three masonry walls reinforced with TRM materials subjected to in-plane cyclic loading. These walls had been built using a traditional construction technique, with solid clay bricks layered with lime mortar. One of them was tested and damaged by in-plane cyclic loading and was subsequently strengthened by a vertical layer of TRM with an overlapping of 200mm. It was again tested until failure in a second test. Also another undamaged specimen had been previously reinforced with the same TRM technique and tested until failure, thus proceeding a third test. Author concludes that TRM also improved the displacement capacity of the masonry walls under cyclic in-plane loads: the final drift amplitudes of the UW were increased by 35% and 20% in the DRW and NDRW, respectively. TRM-strengthening enhanced the behavior in terms of total energy dissipation and higher ductility, which may prove its efficiency in delaying crack growth, thus improving the behavior of severely damaged masonry walls. The research gap found in this study is summarized below.

- The study only focuses on the use of TRM materials for strengthening traditional masonry walls. There is no comparison of the TRM technique with other commonly used strengthening techniques, which can be the scope for future research.
- The study only evaluates the behavior of masonry walls under in-plane cyclic loading. The effectiveness of TRM strengthening under different types of loading, such as out-of-plane loading is not investigated.

Azeez & Thomas (2020)

This paper describes the method for retrofitting of reinforced concrete beams using High Performance Fiber Reinforced Cementitious Composites (HPFRCCs), SIFCON. The use of SIFCON matrix in compression zone of flexural member is supposed to improve ductility and energy absorption capacity of the member. Nine beams of size 150 mm width x 300 mm depth x 1200 mm length with effective span of 1000 mm were casted as per IS 456:2000 providing 8 mm diameter 2 longitudinal bars at tension zone, 6 mm diameter bars as stirrup holders at compression zone .Three beams were retrofitted with SIFCON laminates, three beams were strengthened with SIFCON laminates and remaining three beams were tested under compression cyclic loading as control specimen. The beams were then loaded by two point loading placed along the span of the beam. The actual load carrying capacity of reinforced concrete beam is increased by the method of retrofitting using high performance fiber reinforced cementitious composites (HPFRCCs) called SIFCON, which are directly bonded to the tension side on the soffit of the beam by epoxy adhesive and are tested under compression cyclic loading. For initial loads the cracks obtained are identified by visual examination only. At experimental ultimate load level, the strengthened beams show an increase of 62% with respect to the control specimens and the retrofitted beams shows an increase of 25% with respect to the control specimens. The research gap found in this study is summarized below.

- The paper doesn`t explicit the performance of retrofitted RC beams at different percentage of glass fibres.
- The study only considers a single type of retrofitting method using SIFCON laminates, and it is unclear how this method compares to other retrofitting methods in terms of effectiveness, cost, or practicality.

Abhilash & Manikandan (2016)

This paper investigates the effectiveness of NSM(Near Surface Mounted) and Externally Bounded Reinforcing (EBR) bars for restoring or upgrading the flexural capacity of RC beams. Nine beams of M20 mix designed as per IS:1026:2009 guidelines having dimension of 1000mm*150mm*200mm were casted and tested by two point load method in UTM machine. In this experiment three beams were retrofitted with steel rods , three beams with GFRP rods using NSM technique and three beams were externally bounded with FRP U-wraps after applying 75% of the ultimate load. The result shows that all the beams retrofitted with NSM bars behaved in a ductile manner. The elastic point for steel and GFRP bars was 5.88% and 10.4% higher than that of elastic point of plain reinforced beams respectively and has relatively less deflection compared to control beams. The cracking and crushing pattern of all the beams were similar and were designed to fail in flexure. Flexural and shear cracks in control beam specimens were initiated simultaneously while only flexural crack were propagated with increase of applied loads until failure. It was found that NSM steel strengthened beams increased the ultimate load up to 29% and NSM GFRP strengthened beams increased up to 14% compared to the control beam. NSM GFRP improved greater ultimate capacity compared to NSM steel due to high tensile strength of GFRP bars. Beams retrofitted with NSM rods and external U- wrapping gave significant performance on load deflection behavior. The research gap found in this study is summarized below.

- The paper doesn`t explicit the debonding pattern of the externally bonded reinforcing (EBR) bars.
- The paper considers designing all the beams to fail in flexure but not consider the failure mode of beams in shear.

3. Summary and Conclusion

A combination of different intervention techniques may yield the desired performance. Many factors come into play in the selection of the retrofit solution and therefore no general rules apply. Concrete structures built before the 1970's need to be retrofitted to withstand earthquakes. The choice of the method depends on the building, on its specific requirements, as well as its condition, location, and geometry. Several methods should usually be considered and compared to find the appropriate best one. The effectiveness of the retrofit schemes and their interaction at local level is explored in this study. This paper explored innovative methods for the retrofitting of buildings by conducting a state – of – the – art review on advanced technique and solutions for enhancing the performance of the seismic deficient structural component and presents the detailed information regarding strengthening and retrofitting of the structure. The review also discusses the benefits and future research ideas to enhance the overall efficiency. The development of fracture mechanics based design principles in conjunction with criteria for the selection of materials (fiber, resin, adhesive) and their form is seen to be a critically needed step towards the efficient and safe use of these techniques. The following conclusions can be drawn from this study;

- A number of techniques to utilize the maximum efficiency of FRP, TRM and composite materials were reviewed in this paper such as number of layers of FRP strips with and without FRP anchorage, fully and partially confinement of the TRM, FRP strips anchored with mechanical fasteners, FRP strips at horizontal and inclined pattern, Near Surface Mounting (NSM) and Externally Bonded Reinforcement (EBR). The mechanisms used increased the ultimate load in FRP and TRM concrete beams and interfacial failure plane got shifted from FRP concrete interface to the concrete interface.

- SIFCON laminate Strengthening techniques increased the load carrying capacity of the specimen and shear cracks produced at 45 degree were restricted. Also, the width and length of the cracks was reduced.
- EBR and NSM techniques proved very effective on the flexural behavior of concrete. Flexural response was significantly enhanced.
- The growing understanding of the risk from existing buildings by owners and government is creating a demand for more efficient and reliable analytical methods, as well as innovative techniques for retrofit. A benchmark analytical tool is needed to test and set limitations on simplified nonlinear procedures. A systematic program is needed to fill in the most significant gaps.
- Despite the rapid advances in published guidelines and standards for evaluation and retrofit, engineers must continue to temper their decisions with experience and judgment, primarily based on field observations of real structures under loadings from real ground motions.

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